SF2A 2010
S. Boissier, M. Heydari-Malayeri, R. Samadi and D. Valls-Gabaud (eds)

IRRADIATED DISKS AND PLANET POPULATION SYNTHESIS

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Abstract. Recent planet population synthesis models (Alibert et al. 2010, submitted) have emphasized the key role played by the proto-planetary disk properties in determining the overall planet population characteristics. We present a disk model that takes into account viscous heating and irradiation by a central star. We consider the case of an equilibrium flaring angle. We illustrate the consequences of the resulting changes in the disk structure on the planet population by the synthetic populations corresponding to each of the different structures.

Keywords: planetary systems: formation, protoplanetary disks, planets and satellites: formation

1 Introduction

Properties of disks are important for planet formation. To compute planet formation, models are now built together with their disk environnement. Moreover, population synthesis calculations require the determination of the formation path of many planets which are computer time demanding. Therefore, the aim is to improve the disk model taking account irradiation by a central star using a simplified prescription, checking that the resulting midplane temperature and surface density, that are important to the planet formation, are similar to the one obtained using more detailed disk models.

2 Disk Model

We compute the disc structure and its time evolution following the method 1+1D given by Papaloizou and Terquem (1999), see also Alibert et al. (2005).

To compute the vertical structure we consider the equations in the thin-disk approximation : the hydrostatic equilibrium, the energy conservation and the diffusion equation for the radiative flux. These three equations are integrated, at fixed radius, from the disk "surface" H (defined as the height where the optical depth is 10^{-2}) down to the midplane, $z = 0$, with four boundary conditions, three at the surface and one at the center. Only one value of H, allows to simultaneously fulfil all the boundary conditions. Thus, we have the pressure $P(z, r_o)$, the temperature $T(z, r_o)$ and the radiative flux $F(z, r_o)$, for z equal 0 to H, and for each radius r_o. Then, we calculate the viscosity ν using the standard α-parametrization (Shakura and Sunyaev 1973). Subsequently, we compute the time evolution of the disc considering the well-known diffusion equation (Lyndell-Bell and Pringle 1974). To solve the diffusion equation we need to specify two boundary conditions : the inner and outer radius.

In order to explore the effect of irradiation. We assume that all the disk is irradiated, neglecting all possible shadowing effects. The irradiation effect is included by modifing the temperature boundary condition of the vertical structure. The irradiation temperature is derived in Hueso and Guillot (2005) :

$$T_{irr} = T_* \left[\frac{2}{3\pi} \left(\frac{R_*}{r} \right)^3 + \frac{1}{2} \left(\frac{R_*}{r} \right)^2 \left(\frac{H_p}{r} \right) \left(\frac{\mathrm{d} \ln H_p}{\mathrm{d} \ln r} - 1 \right) \right]^{\frac{1}{4}}, \tag{2.1}$$

where R_* is the stellar radius, r is the distance to the star and H_p is the pressure scale height. The flaring angle, $\mathrm{d} \ln H_p / \mathrm{d} \ln r$, is taken at its equilibrium value 9/7 (Chiang and Goldreich 1997).

In Fig. 1 we compare the mid-plane temperature and surface density in a disk of constant accretion rate ($\dot{M} = 10^{-8}\, M_\odot\, yr^{-1}$) with the results of D'Alessio et al. (1998).

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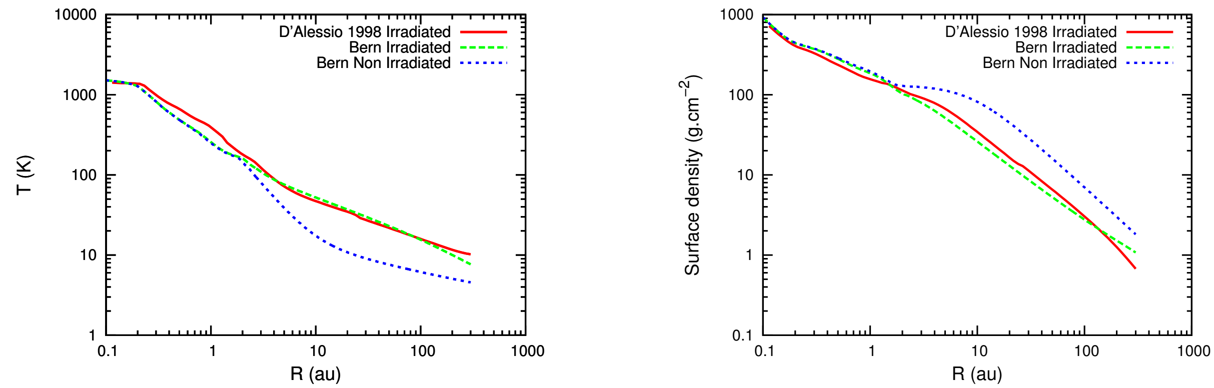

Fig. 1. *Left*: Temperature midplane. *Right*: Surface density. The model of D'Alessio et al. (1998) in red solid line, the model of Bern with irradiation in green long dashed line, and without irradiation in blue short dashed.

We first note that the temperature is substantially higher in the outer parts of the disk when irradiation is included. We obtain a good match for the midplane temperature and surface density.

3 Population Synthesis Model

In Fig. 2 we show the effects of irradiation on the expected planet population. We compute the theoretical planet populations, using the same parameters for irradiated and no-irradiated cases.

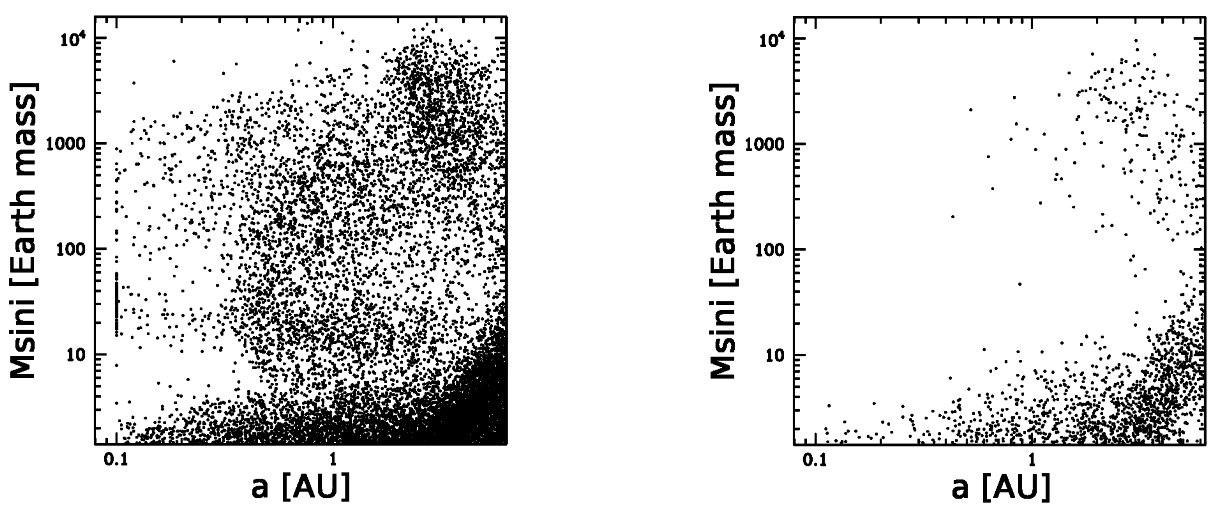

Fig. 2. Mass versus semi-major axis for synthetic planets. *Left* panel: without irradiation effects. *Right* panel : including irradiation effects.

Comparing the two panels, it is obvious that stellar irradiation has a strong effect on the expected planet population : hot planets do not exist anymore. The effect is as big in the nominal model because we use a larger reducing factor for type I migration, $f_I = 10^{-3}$. Therefore, the changes in population are due to assumptions in the model more than in physics. Hence, if we use $f_I = 10^{-1}$ instead 10^{-3}, we retrieve a few hot planets.

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